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Supplement 3-



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

APOLLO 5 MISSION REPORT
COMMUNICATIONS SYSTEM PERFORMANCE

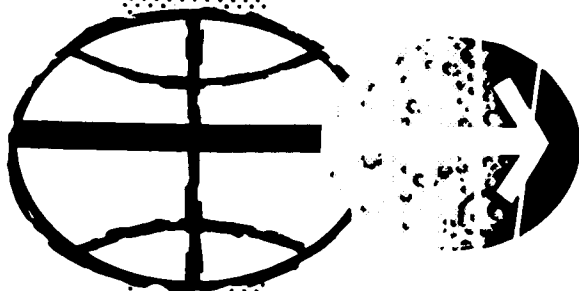
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JUNE 1969

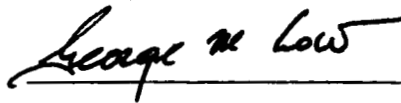
APOLLO 5 MISSION REPORT

COMMUNICATIONS SYSTEM PERFORMANCE

PREPARED BY

Mission Evaluation Team

APPROVED BY

A handwritten signature in cursive script, reading "George M. Low", is written over a horizontal line.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

June 1969

INTRODUCTION

This document supplements Apollo 5 Mission Report, MSC-PA-R-68-7, and presents a detailed communications system evaluation based on data that were not available at the time the basic report was published.

The Apollo 5 mission, the first with a lunar module, was flown on January 22 and 23, 1968. The mission was evaluated in terms of expected performance, and the analysis of the communications system performance was presented in section 6.8 of the mission report. However, several items concerning communications system performance remained unanswered and will be discussed in this supplemental report.

SUMMARY

Four questionable areas relative to communications system performance were still under investigation when the Apollo 5 Mission Report was published. These have now been resolved.

a. An excessive number of incorrect S-band ranging acquisitions were experienced during Apollo 5. These were found to have resulted from the spacecraft antenna facing away from the Manned Space Flight Network (MSFN) site antenna. Moreover, from this orientation, the spacecraft antenna (a fixed, nonswitchable, omnidirectional unit) had poor radiation distribution characteristics. Therefore, at these times, erratic communications system performance was not unusual, and resulted in incorrect ranging acquisitions.

b. The spacecraft-received UHF signal power showed abrupt fluctuations which adversely affected command reception. An intermittent spacecraft fault was determined to be the cause.

c. The measured S-band communications system performance was compared with predictions based on actual flight parameters. The data compared to within plus or minus 3 dB when the look angle between the spacecraft and MSFN site was in the favorable region of the spacecraft antenna pattern and the site elevation angle was above 5 degrees. Specifically, the average amount that the measured values varied from the predicted values was approximately 3 dB (both high and low). Included in these averages were differences in both directions of up to 10 dB. A 10-dB dip below predictions could, at lunar distances, adversely affect communication system performance.

d. The telemetry channel performance during prelaunch checkout was worse than had been predicted. This was attributed to a failure of the predictions to consider a system noise temperature increase caused by an MSFN site elevation angle of less than 5 degrees and to an attenuator inserted between the site antenna and preamplifier.

The most significant result of this investigation was that virtually all of the numerous instances of inadequate S-band signal strength were directly attributable to unfavorable spacecraft orientation. Furthermore, S-band communications would have been greatly improved if the capability to switch to the optimum spacecraft antenna had existed. However, this is strictly an unmanned lunar module problem and during all future manned missions, the crew will have the capability to improve communications by switching to the antenna most nearly pointing to the ground station.

COMMUNICATIONS SYSTEM ANALYSIS

The following paragraphs present the results of the additional investigation into the communications system performance.

INCORRECT RANGE CODE ACQUISITIONS

During the mission, the downlink received S-band carrier power exhibited large, rapid variations. There were also times when it was weak. These periods of low signal level and rapid fluctuations caused some operational problems; that is, an excessive number of incorrect ranging acquisitions. The problems were found to have occurred invariably when the active spacecraft antenna was facing away from the ground station. In this region, the antenna pattern is heavily scalloped and most unfavorable. This conclusion is significant considering that the lunar module was launched in a fixed antenna configuration (omni 2), whereas manned lunar modules will have the capability to improve communications by switching to the antenna that is most nearly pointing to earth.

Six station passes had incorrect range code acquisitions which could be attributed to fast signal variations or low signal levels. Data for five of the six passes were available and have been analyzed.

Figures 1 through 5 and table I show that all but one of the incorrect acquisitions (the one at the Ascension site during revolution 5 at 6:40:52) occurred when the look angles between the spacecraft and MSFN site were within the unfavorable region of the antenna pattern, thus resulting in weak received signals. However, could the omni 2 antenna

have been selected, the downlink received carrier power would have been improved by 17 to 26 dB. The only incorrect ranging acquisition during favorable antenna coverage was caused by an attempt to achieve a range acquisition during a site antenna keyhole when the downlink received carrier power was less than minus 140 dBm.

The incorrect range code acquisition at 4:41:28 (Texas site, revolution 3) has been selected to show that antenna switching from omni 2 to omni 1 would have provided favorable communications coverage. Figure 6 shows a comparison of the gains of the active (omni 2) and inactive (omni 1) antennas. The omni 2 gain was weak and rapidly varying at the time of the ranging acquisition attempt, whereas the inactive antenna gain would have been consistently higher, resulting in better communications coverage. Figure 7 is a typical example of the relative gains of omni 1 and omni 2 antennas. This figure shows overlapping coverage, which allows for switching time, and indicates that a combination of both antennas would have provided 360-degree coverage in the plane with theta of 90 degrees.

UHF RECEIVED SIGNAL STRENGTH ANOMALY

Abrupt increases and decreases in the received UHF signal power at the command receiver were observed throughout the mission. During the time period following the abrupt increases, the received signal power corresponded to predictions. However, during time periods following the abrupt decreases, the received signal power was approximately 40 dB below the predicted levels. This decrease caused the received signal power to be below the message acceptance threshold of the command receiver.

Since publication of the applicable Anomaly Report, new data have become available. The principal difference between the data available then and those presented in this section is the addition of received UHF signal strength predictions, MSFN antenna elevation angles, and spacecraft-to-site look angles. All of these additional data are based on measured spacecraft attitudes and the best-estimate trajectory. Consequently, additional investigation was conducted.

The Anomaly Report listed five possible sources of the problem:

- a. Low MSFN antenna elevation
- b. Intermittent MSFN transmitter operation
- c. Improper operation of one of the spacecraft antennas
- d. Poor antenna coverage
- e. Intermittent spacecraft hardware operation.

The Anomaly Report presented the conclusion that intermittent spacecraft hardware (source e) was the problem. This supplement presents the results of additional analyses made on the first four sources. An analysis of the fifth source was presented at length in the Anomaly Report and will not be discussed further.

The first source of signal strength fluctuations — low site elevation angles — was more prevalent than had previously been expected. Several of the abrupt changes in received UHF signal strength during the Carnarvon and Hawaii coverages were discovered to occur below a site elevation angle of 5 degrees. These particular fluctuations, previously attributed to a suspected spacecraft hardware fault, are now considered to be operational problems (due to the effects of multipath) and are not related to the problem under investigation. (The affected station passes are denoted in table II by asterisks.)

The second possible source, intermittent ground transmitter operation, was considered unlikely. Further analysis has removed this as a possibility because the Texas, Carnarvon, and Merritt Island stations, and the Rose Knot Victor ship all experienced passes which were both consistent with predictions and approximately 40 dB below predictions during part or all of the pass. Therefore, if a faulty site transmitter caused the fluctuations, all four station transmitters would have had to experience the same type of intermittent operation. This is considered improbable.

A third unlikely source was improper operation of one of the spacecraft antennas. This was also removed as a possibility by close examination of data from the Texas station. As shown in table II, measured received signal strength agreed with predictions for the pass over the Texas station for the first revolution. However, during the revolution 2 pass over this station, the signal strength was consistently 40 dB below predictions. Significantly, during both these passes over the Texas station, the spacecraft-to-site look angle progressed from one antenna to the other. Since performance was consistent from one antenna to the other, an inoperative antenna did not cause the problem.

The fourth source was the possibility that the best-estimate trajectory and measured spacecraft-to-site look angles would reveal areas of poor antenna coverage coincident with the signal strength fluctuations. This, however, was not the case. For example, figures 8 through 11 show comparisons of measured and predicted received UHF signal strength for passes over the Bermuda, Texas, and Carnarvon stations. These passes are typical and show that the areas of signal degradation could not be predicted and therefore, were not due to the effects of antenna patterns or poor spacecraft-to-site look angles.

It is concluded that the abrupt changes in received UHF signal strength were not the result of ground transmitter problems, an inoperative spacecraft antenna, or poor antenna patterns. In ruling out these possibilities, the additional investigation has confirmed the original conclusion, isolating the fault of the intermittent operation to the flight hardware. Specifically, the fault can be isolated either to the RF stage of the digital command assembly or to the coaxial cable assembly connecting this assembly to the diplexer.

S-BAND RF SYSTEM PERFORMANCE

Five typical station passes (listed in table III) were selected for comparison of measured received downlink S-band carrier power with predicted values. The predictions were based on fullscale antenna patterns for omni 2, measured spacecraft attitudes, and the best-estimate trajectory. In general, as shown by table III and figures 12 through 16 the measured and predicted average S-band carrier power levels were within approximately 3 dB when the spacecraft-to-site look angle was in the favorable region of the omni 2 antenna pattern and the site elevation angle was above 5 degrees. Specifically, the average amount that the predicted values varied from the measured values was approximately 3 dB (both above and below). Included in these averages were differences in both directions of up to 10 dB. If the S-band carrier power should dip 10 dB below predictions, communication system performance at lunar distances could be adversely affected.

PRELAUNCH BIT ERROR RATE DISCREPANCY

Prior to the launch of Apollo 5, bit-error-rate tests were conducted at Kennedy Space Center primarily to determine whether incidental phase modulation existed within the spacecraft. No such modulation was found; however, during the test, the measured bit error rates (as compared with received carrier power) were discovered to be 1 to 2 dB lower than had been predicted.

Reevaluation of the prediction calculations revealed two faulty areas: antenna temperature and circuit loss ratio. The original prediction of antenna temperature assumed a 5-degree antenna elevation angle at the Merritt Island Site, resulting in an antenna temperature of 90° K. For this test, however, a zero degree elevation angle with a 150° K antenna temperature was determined to be more realistic.

Also, the original prediction assumed a 0.5 dB circuit loss between the antenna and preamplifier at Merritt Island. This test, however, required additional attenuation.

The combined effect of the additional attenuation and the updated antenna noise temperature resulted in an increase in the system noise temperature from 300° K to 480° K. A 2 dB increase in system noise that caused a shift in the predicted bit error rate curve resulted in much better correlation with the measured bit error rate curve. Figure 17 shows the measured and predicted bit error rates for the primary transponder with a measured modulation index of 1.12 radians. Figure 18 shows both measured and predicted bit error rates for the secondary transponder with a measured modulation index of 1.03 radians. These two figures show that the predictions based on the higher system noise temperature of 480° K agree well with the measured results.

In conclusion, the discrepancy between the measured and predicted prelaunch bit error rates was probably caused by an oversight in calculation of the system noise temperature.

TABLE I.- INCORRECT S-BAND RANGING ACQUISITIONS

Station	Revolution	Time, hr:min:sec	Figure number	Comments
Guaymas	2	3:06:28	1	Incorrect acquisition attributed to rapid signal level variations causing sharp correlation voltage variations during acquisition. The spacecraft-to-site look angle was in the scalloped (unfavorable) region of the omni 2 antenna pattern. The omni 1 antenna would have provided approximately 25 dB stronger carrier power than omni 2.
		3:06:40	1	Incorrect acquisition attributed to rapid signal level variation. The spacecraft-to-site look angle was in the scalloped region of the omni 2 antenna pattern. The omni 1 antenna would have provided approximately 23 dB stronger carrier power.
Texas	3	4:41:28	2	Incorrect acquisition resulted from rapid signal level variation. The spacecraft-to-site look angle was in the scalloped region of the omni 2 antenna pattern. The omni 1 antenna would have provided approximately 17 dB stronger carrier power.
Ascension	5	6:40:52	3	Incorrect acquisition resulted from rapid signal level variation. This acquisition was attempted during antenna keyhole when the downlink received carrier power was less than minus 140 dBm. Antenna patterns at 6:40:52 indicate that had the Ascension antenna not been tracking through the keyhole, the downlink received carrier power would have been greater than minus 90 dBm and a ranging attempt would probably have been successful.
Carnarvon	5	7:13:10	4	Incorrect acquisition attributed to low signal level. The spacecraft-to-site look angle was in the scalloped region of the omni 2 antenna pattern. The omni 1 antenna would have provided approximately 18 dB stronger carrier power.
		7:13:34	4	Incorrect acquisition attributed to low signal level. The spacecraft-to-site look angle was in the scalloped region of the omni 2 antenna pattern. The omni 1 antenna would have provided approximately 21 dB stronger carrier power.
		7:13:52	4	Incorrect acquisition attributed to low signal level. The spacecraft-to-site look angle was in the scalloped region of the omni 2 antenna pattern. The omni 1 antenna would have provided approximately 25 dB stronger carrier power.

TABLE I.- INCORRECT S-BAND RANGING ACQUISITIONS - Concluded

Station	Revolution	Time, hr:min:sec	Figure number	Comments
Hawaii	5	7:39:16	5	Incorrect acquisition attributed to low signal level caused by sidelobe track. The spacecraft-to-site look angle was in the scalloped region of the omni 2 antenna pattern. The omni 1 antenna would have provided approximately 23 dB stronger carrier power. The site-to-spacecraft elevation angle was approximately 1.6 degrees during this acquisition attempt.
		7:42:04	5	Incorrect acquisition attributed to low signal level because of a sidelobe track. The spacecraft-to-site look angle was in the scalloped region of the omni 2 antenna pattern. The omni 1 antenna would have provided approximately 19 dB stronger carrier power.
		7:42:52	5	Incorrect acquisition occurred during attempt to gain main beam auto-track. The spacecraft-to-site look angle was in the scalloped region of the omni 2 antenna pattern. The omni 1 antenna would have provided approximately 25 dB stronger carrier power.
		7:43:16	5	Incorrect acquisition. The spacecraft-to-site look angle was in the scalloped region of the omni 2 antenna pattern. The omni 1 antenna would have provided approximately 25 dB stronger carrier power.
		7:43:28	5	Incorrect acquisition. The spacecraft-to-site look angle was in the scalloped region of the omni 2 antenna pattern. The omni 1 antenna would have provided approximately 26 dB stronger carrier power.
Guam	5	7:26:58	-	Incorrect acquisition. No data available for analysis.
		7:27:16	-	Incorrect acquisition. No data available for analysis.

TABLE II.- UHF SIGNAL STRENGTH SUMMARY

Station	Revolution	Figure number	UHF signal strength for 5 to 5 deg elevation	Predominant antenna
Carnarvon	1	8	At adapter/lunar module antenna switchover, the signal strength jumped 6 dB above predictions and then dropped 40 dB abruptly at 0:54:20 and remained 40 dB below predictions for the remainder of the pass.	Minus Z after switchover at 0:53:56
Texas	1	-	Good for entire pass and corresponds with predictions.	Rotated from minus Z to plus Z
Bermuda	2	9	Good for entire pass except for a momentary drop which is in agreement with predictions.	Rotated from minus Z to plus Z
Carnarvon*	2	-	Dropouts prior to 2:25:02 because of low elevation angle. Good for entire pass except for momentary drop at 2:28:19.	Minus Z
Texas	2	10	Low for entire pass. Approximately 40 dB below predictions.	Rotated from minus Z to plus Z
Merritt Island	2/3	-	Low for entire pass.	Information not available
Carnarvon*	3	16	Good until 4:00:02, when abrupt drop 40 dB below predictions. Abrupt rise at 4:02:22; then agreed with predictions. Dropouts prior to 3:59:16 because of low elevation angles.	Minus Z
Texas	3	-	Good for entire pass.	Rotated from plus Z to minus Z
Carnarvon*	4	-	Low elevation pass.	
Hawaii*	4	-	Low elevation pass.	
Texas	4	-	Good for entire pass and followed predictions.	Rotated from plus Z to minus Z
Carnarvon	5	-	Low elevation pass.	
Hawaii*	5	-	Good for 5 to 5 degrees; dropouts at elevation angles less than 5 degrees.	Plus Z

*Abrupt changes in received signal strength have been attributed to low ground station antenna elevation angle.

TABLE III.- RECEIVED S-BAND CARRIER POWER PREDICTIONS

Station	Revolution	Figure number	Comments
Carnarvon	1	12	Measured and predicted carrier powers agree very closely for the entire station pass. The spacecraft-to-site look angles remained in the favorable region of the active omnidirectional antenna.
Texas	1	13	Periods of both good and poor correlation between predicted and measured received carrier power levels can be seen. Except for dropouts during switchover to the power amplifier (approximately 1:33), the measured carrier power followed predictions fairly well until 1:35, when the look angle entered the scalloped region at a theta of 296 degrees. For the next several minutes, the comparison ranged from poor to fair again, as the look angle passed across the scalloped region.
Carnarvon	3	14	The trend of the measured and predicted carrier power showed fair correlation except for a few scattered time intervals. It can be seen that the spacecraft-to-site look angle entered the heavily scalloped portion of the antenna pattern shortly before 4:03, where it remained for the rest of the pass.
Guaymas	4	15	Measured and predicted carrier powers agreed very closely during the last third of the station pass. For the first two-thirds of the pass, the spacecraft-to-site look angles were in the unfavorable region of the antenna pattern, which resulted in poor correlation between predicted and measured data.
Texas	4	16	Good correlation between measured and predicted received carrier power existed except for approximately 2-1/2 minutes, during which the line-of-sight between the ground station and the spacecraft was in the site antenna keyhole and the site antenna was tracking on a sidelobe. The spacecraft look angles remained in the favorable region of the antenna pattern during this pass.

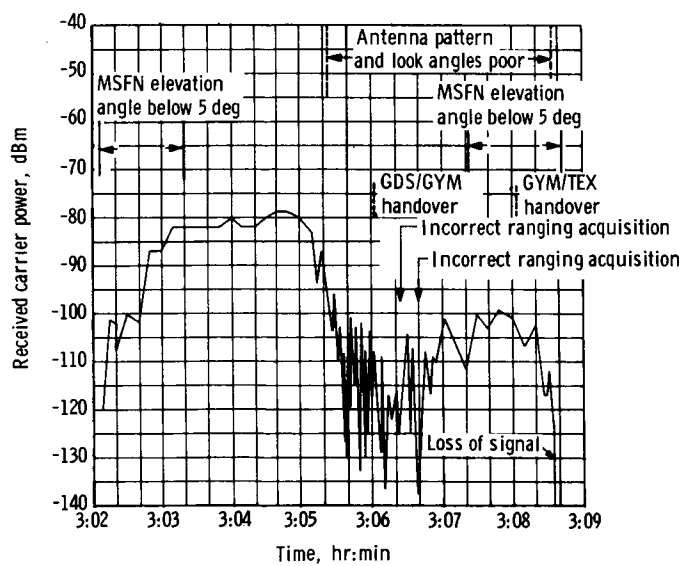
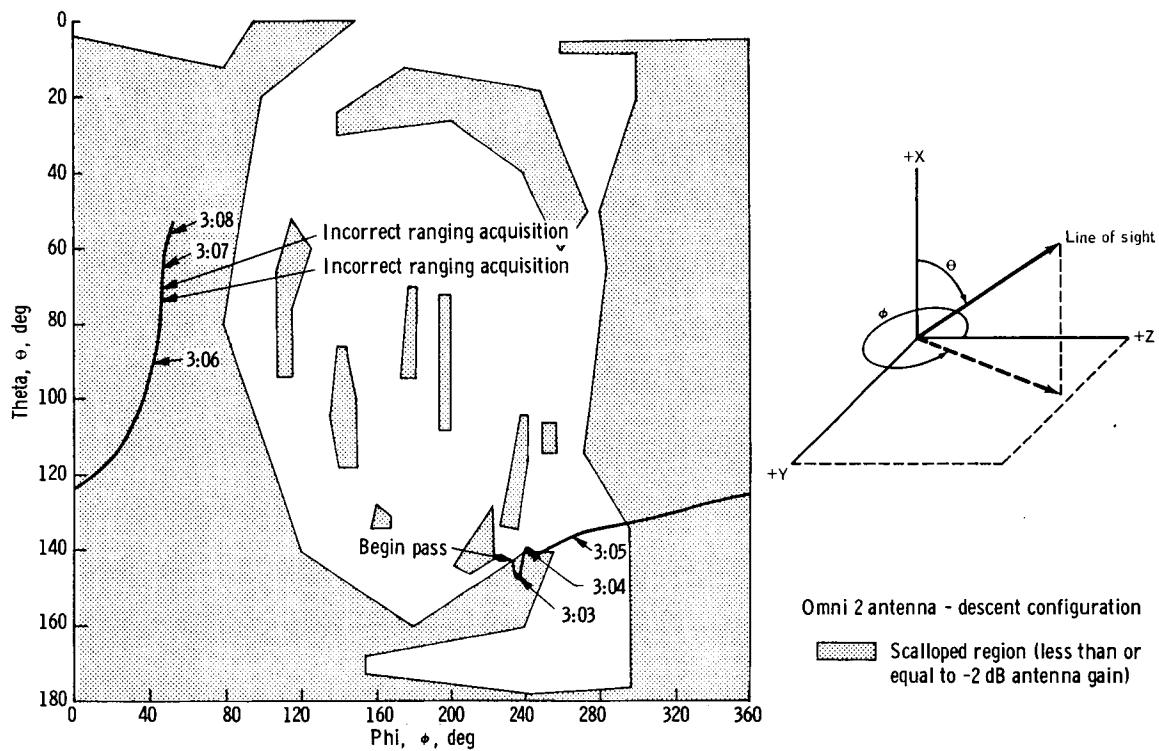


Figure 1. - Received S-band downlink carrier power and look angles, Guaymas, revolution 2.

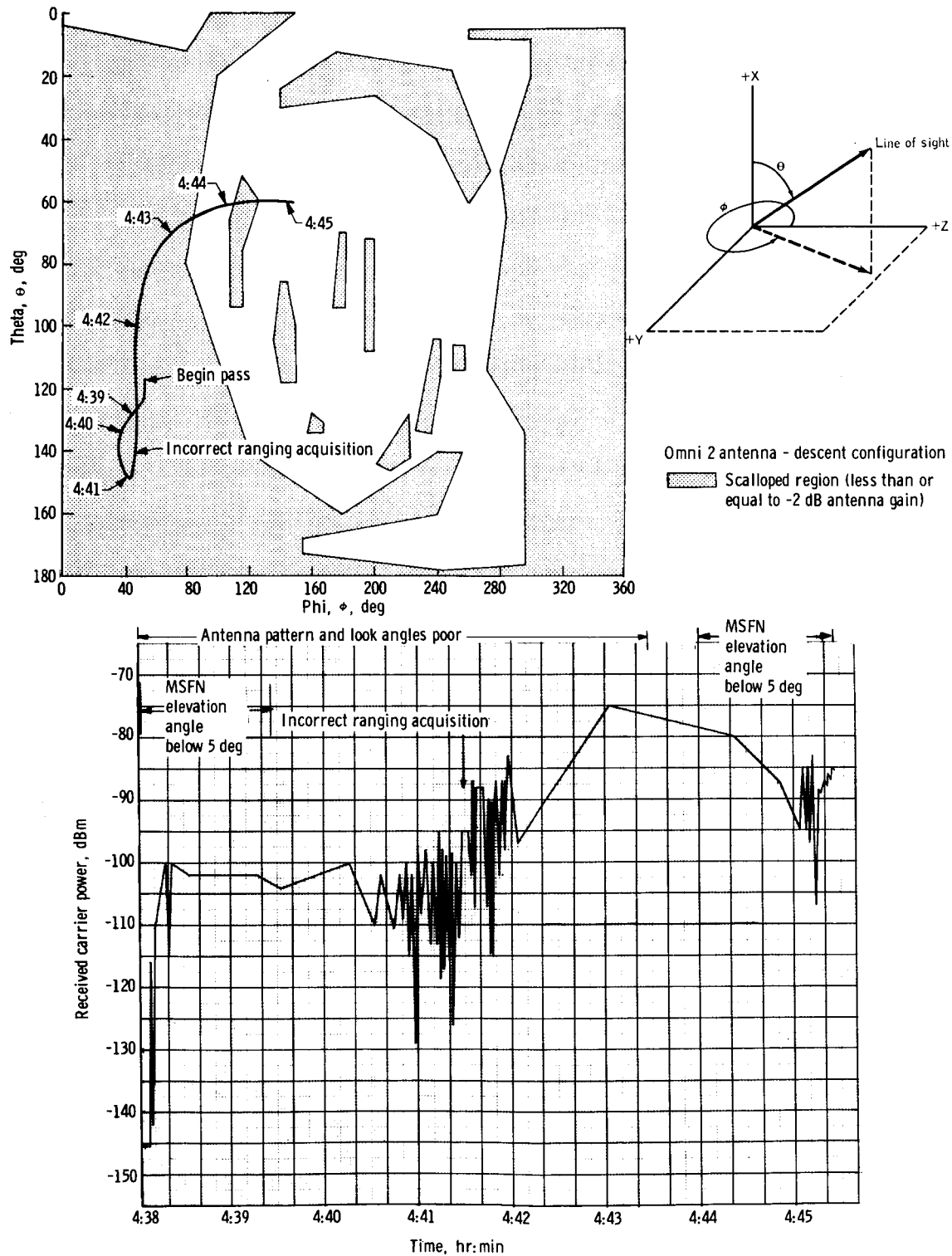


Figure 2. - Received S-band downlink carrier power and look angles, Texas, revolution 3.

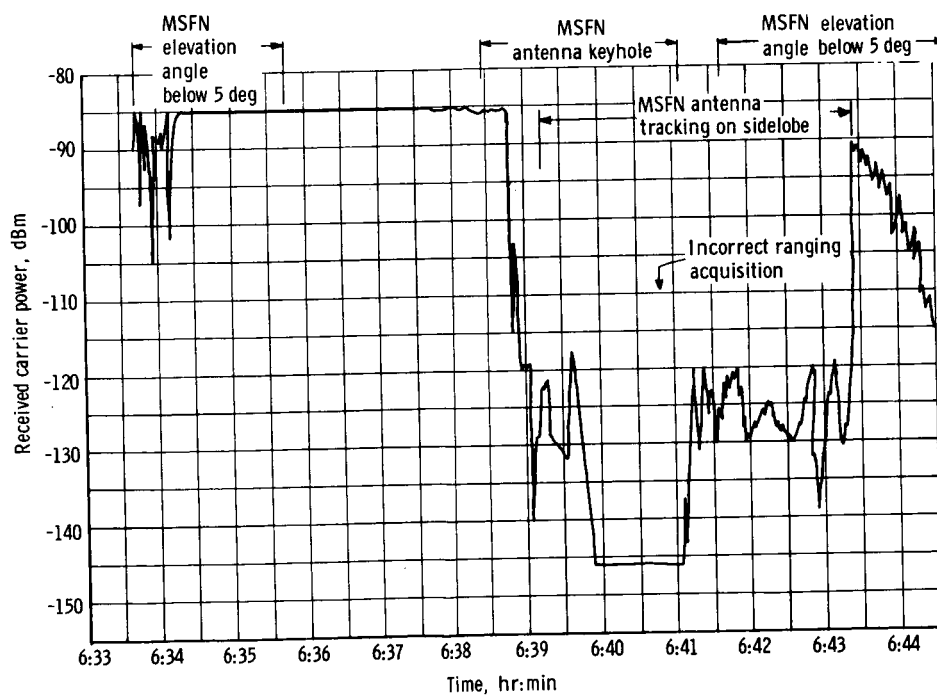
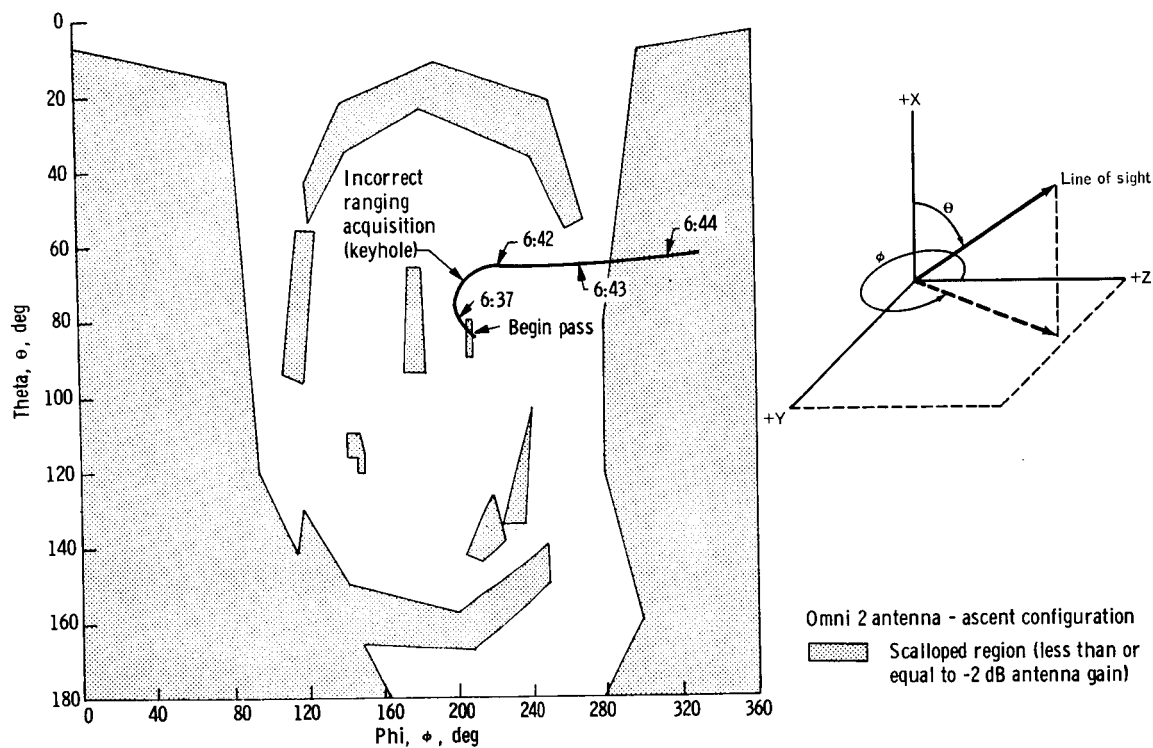


Figure 3.- Received S-band downlink carrier power and look angles, Ascension, revolution 5.

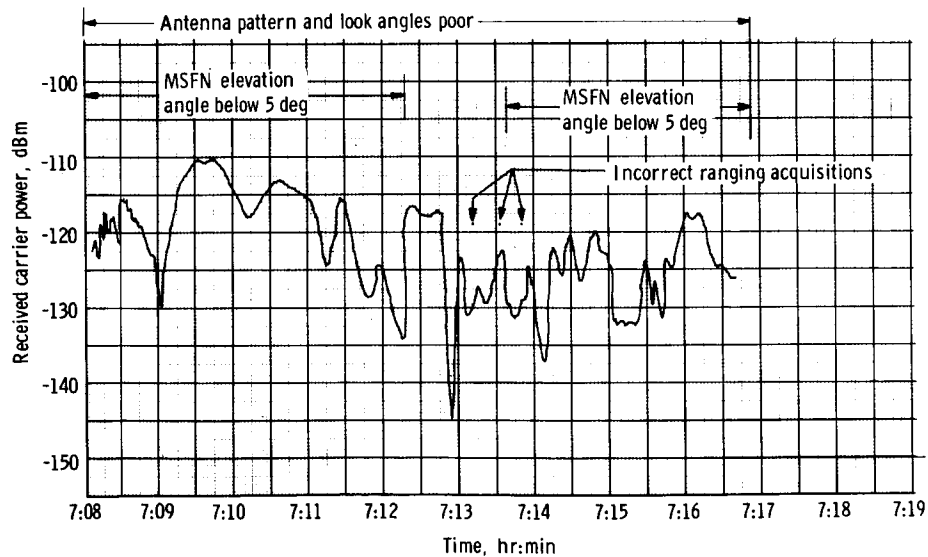
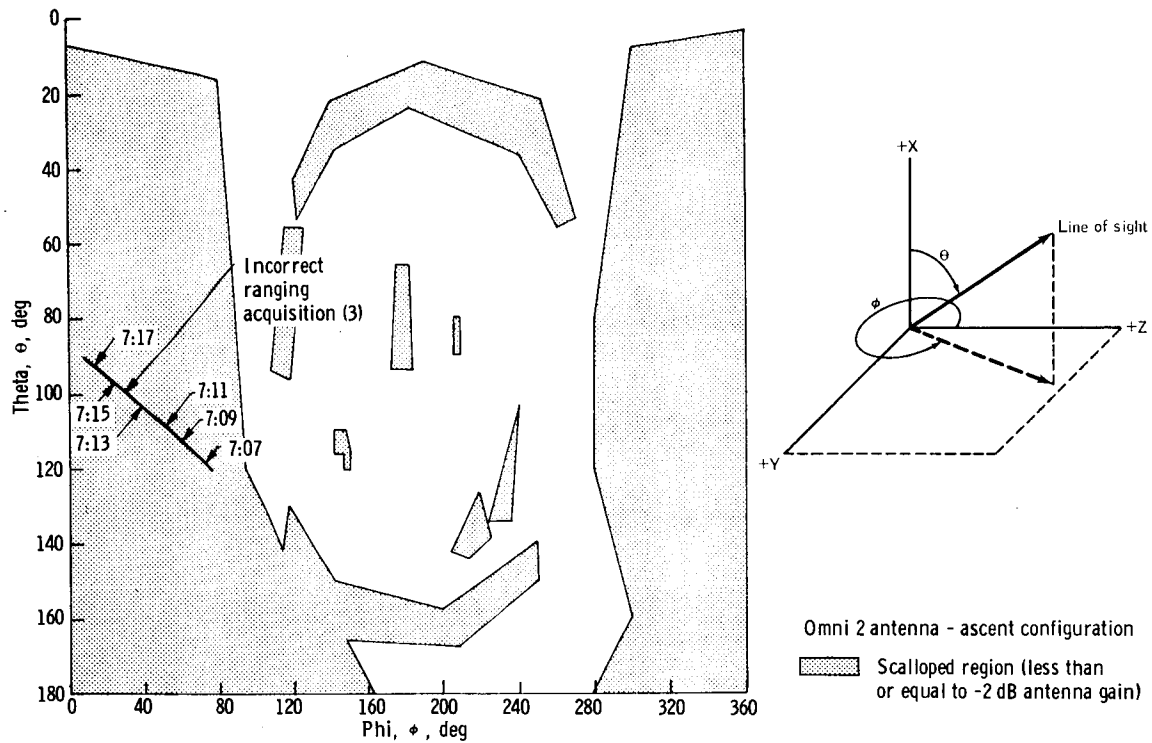


Figure 4. - Received S-band downlink carrier power and look angles, Carnarvon, revolution 5.

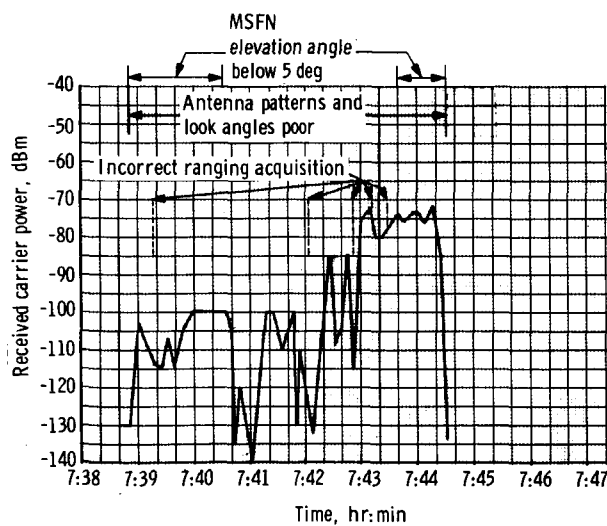
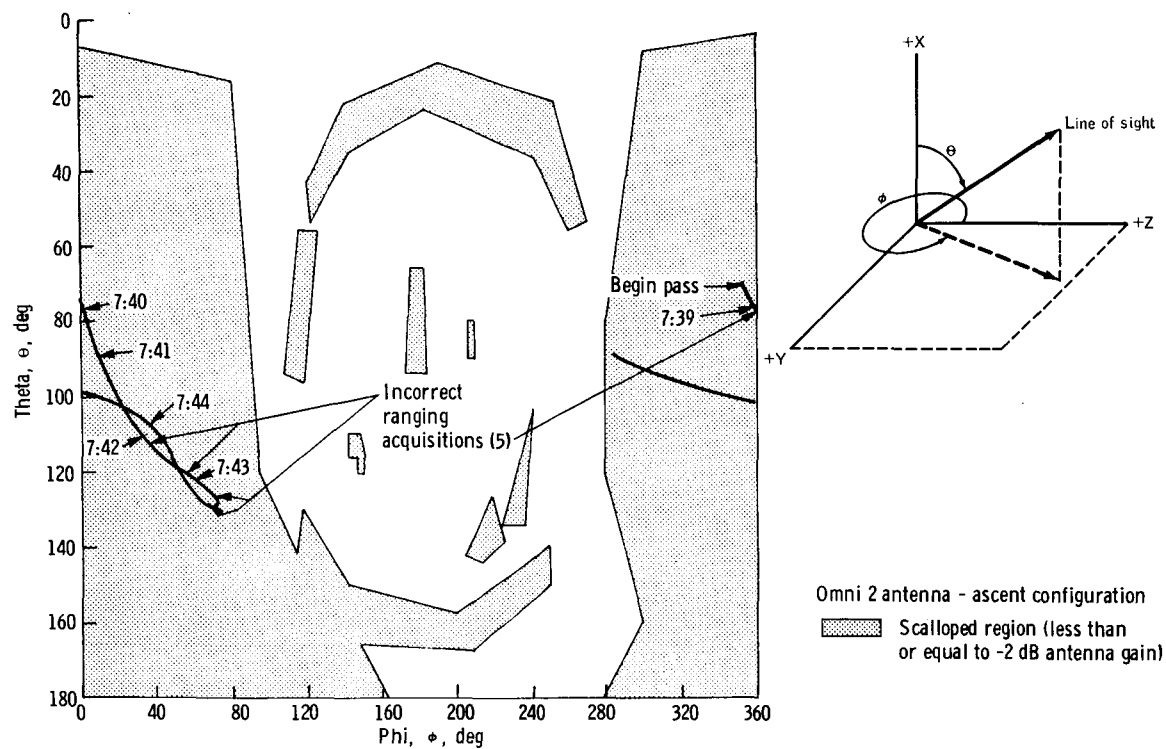


Figure 5. - Received S-band downlink carrier power and look angles, Hawaii, revolution 5.

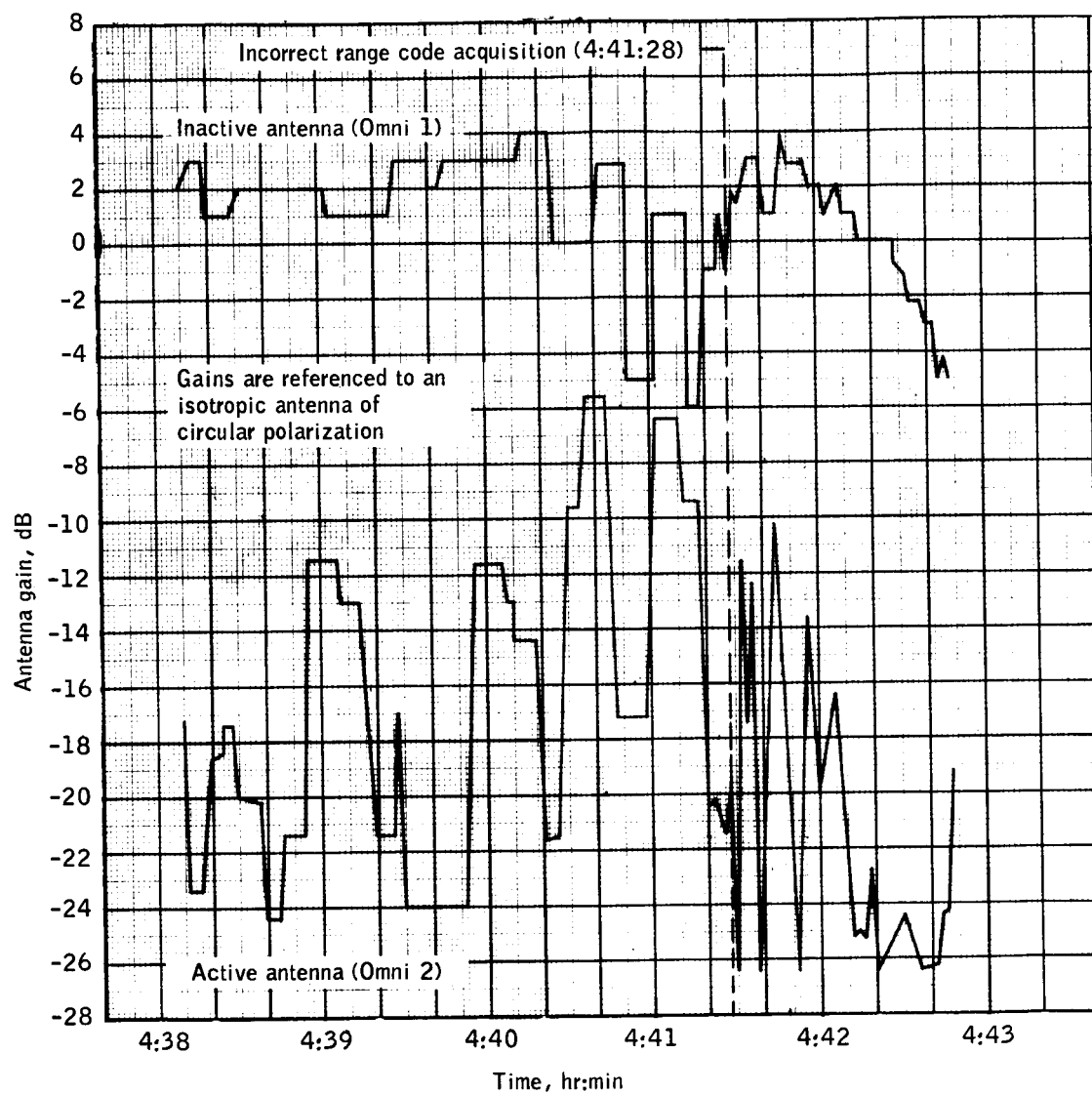


Figure 6.- Active and inactive antenna gains, Texas, revolution 3.

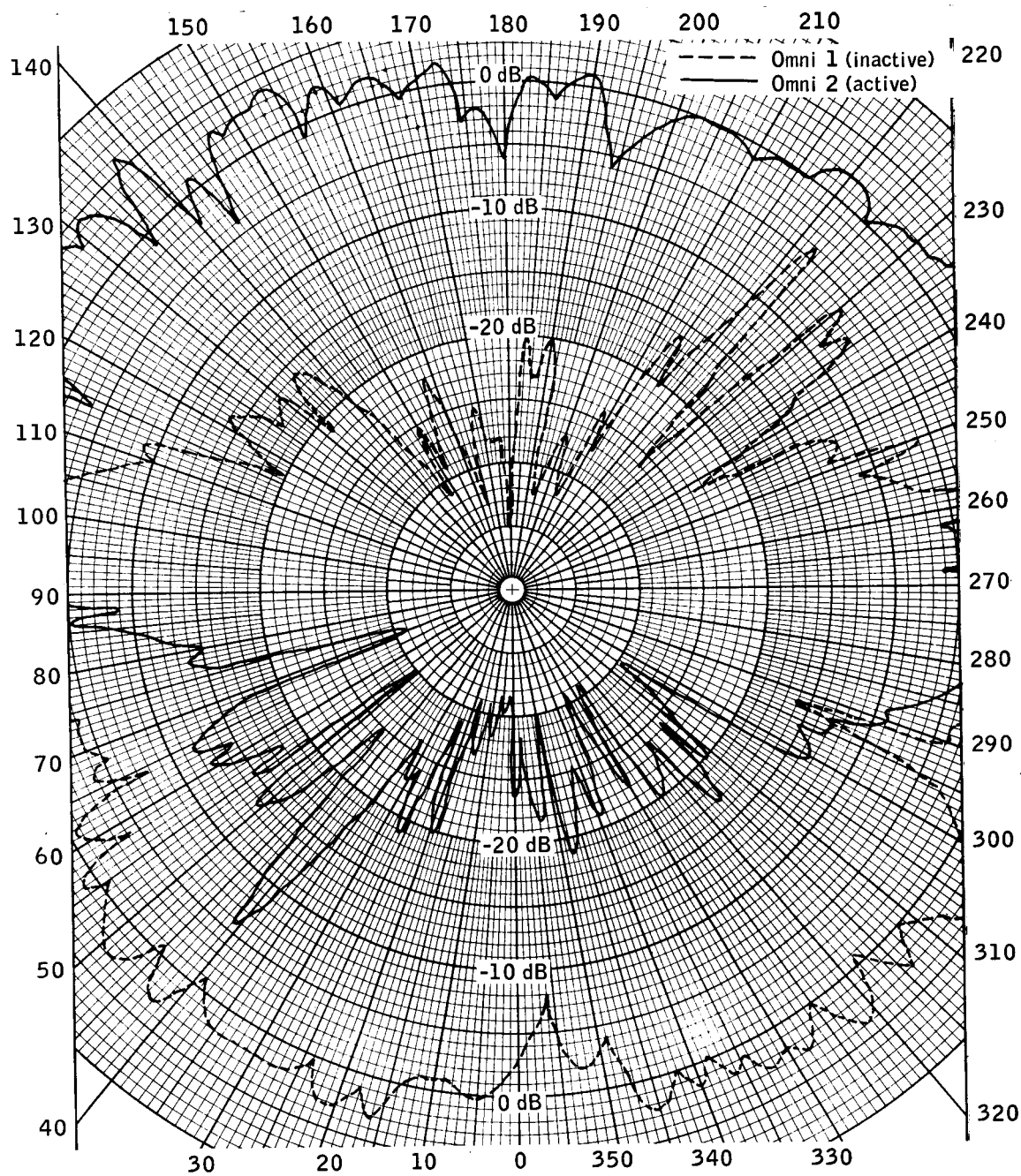


Figure 7.- Omnidirectional gain plot, descent configuration ($\theta = 90^\circ$).

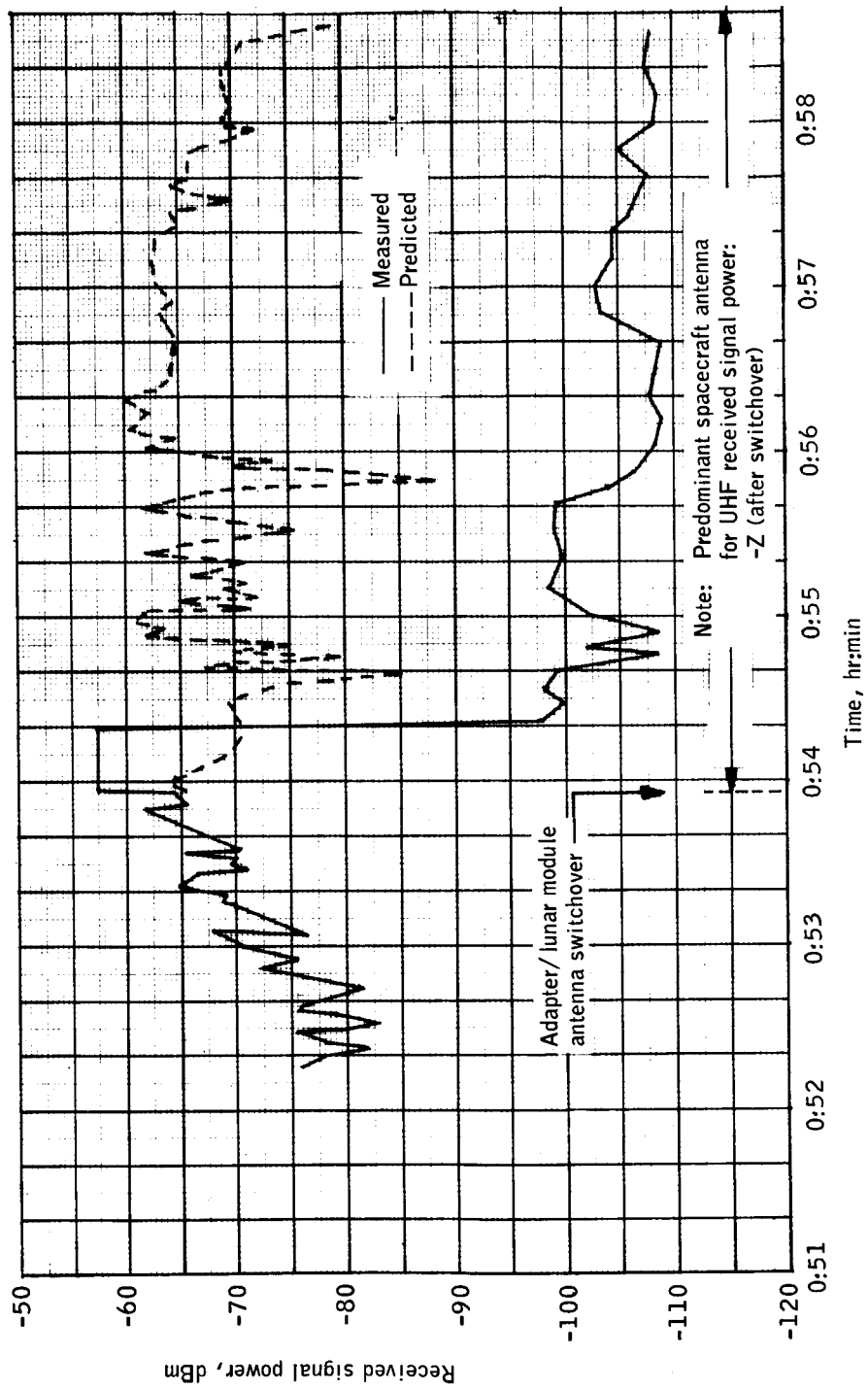


Figure 8.- Total received UHF power, Carnarvon, revolution 1.

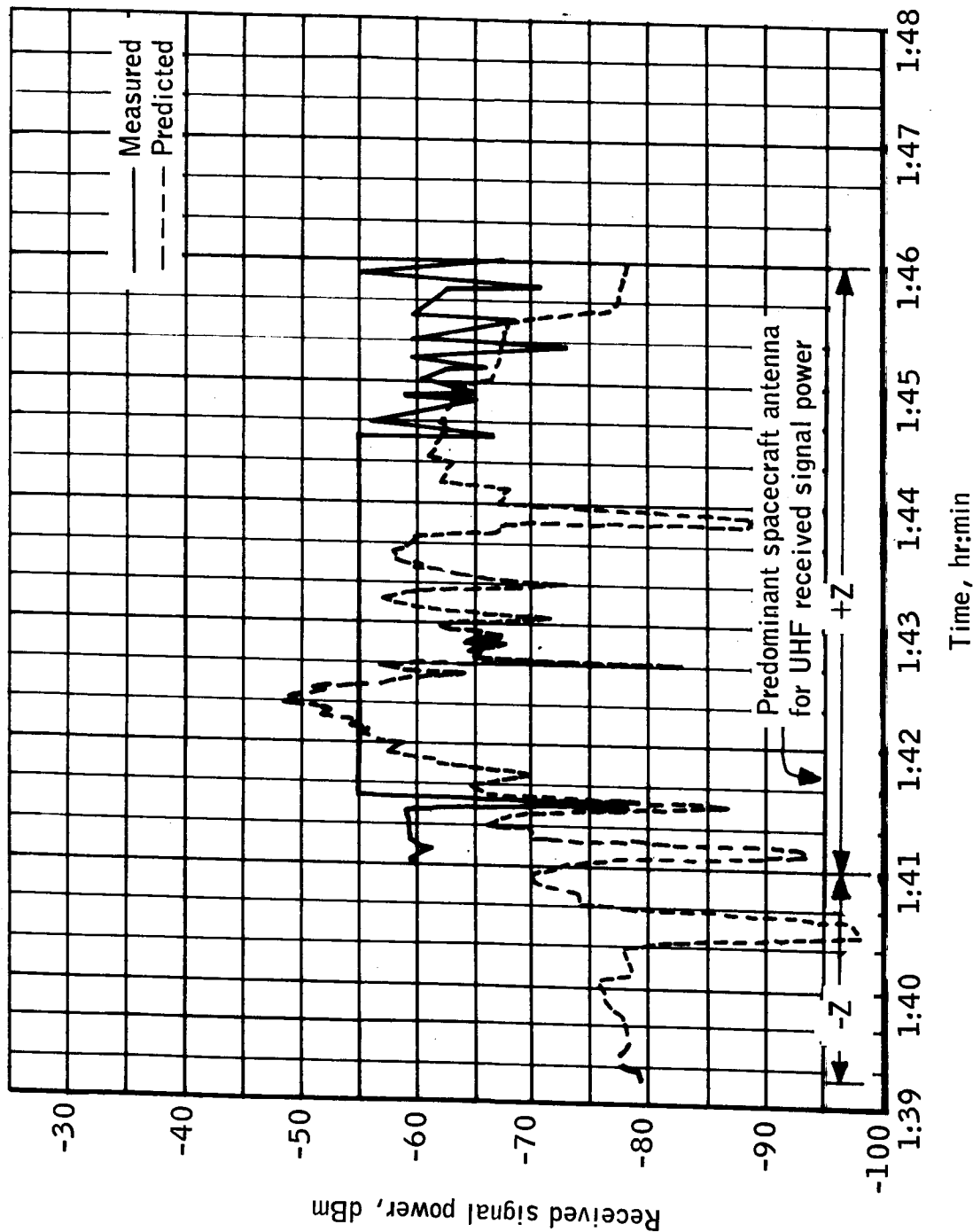


Figure 9.- Total received UHF power, Bermuda, revolution 2.

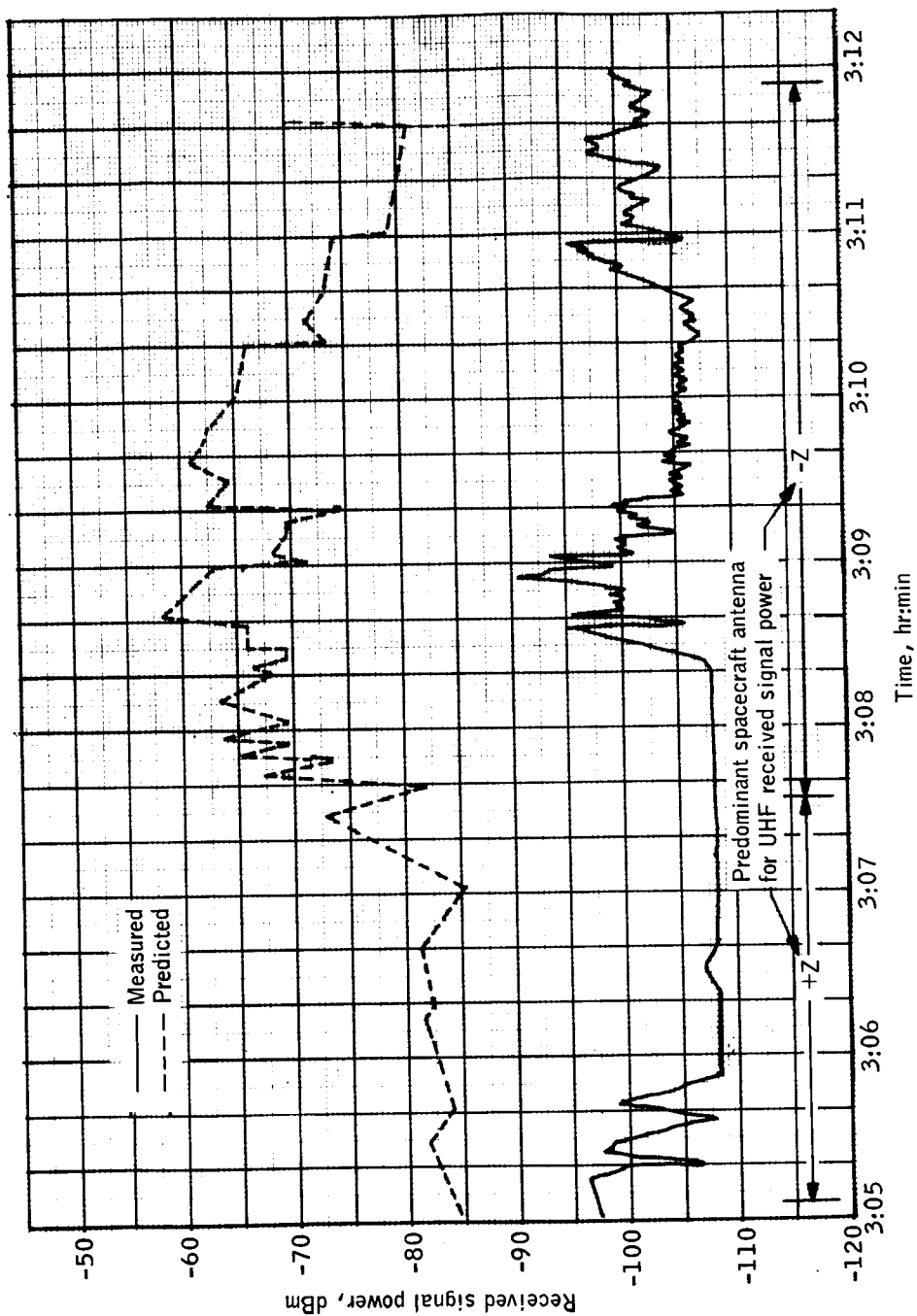


Figure 10.- Total received UHF power, Texas, revolution 2.

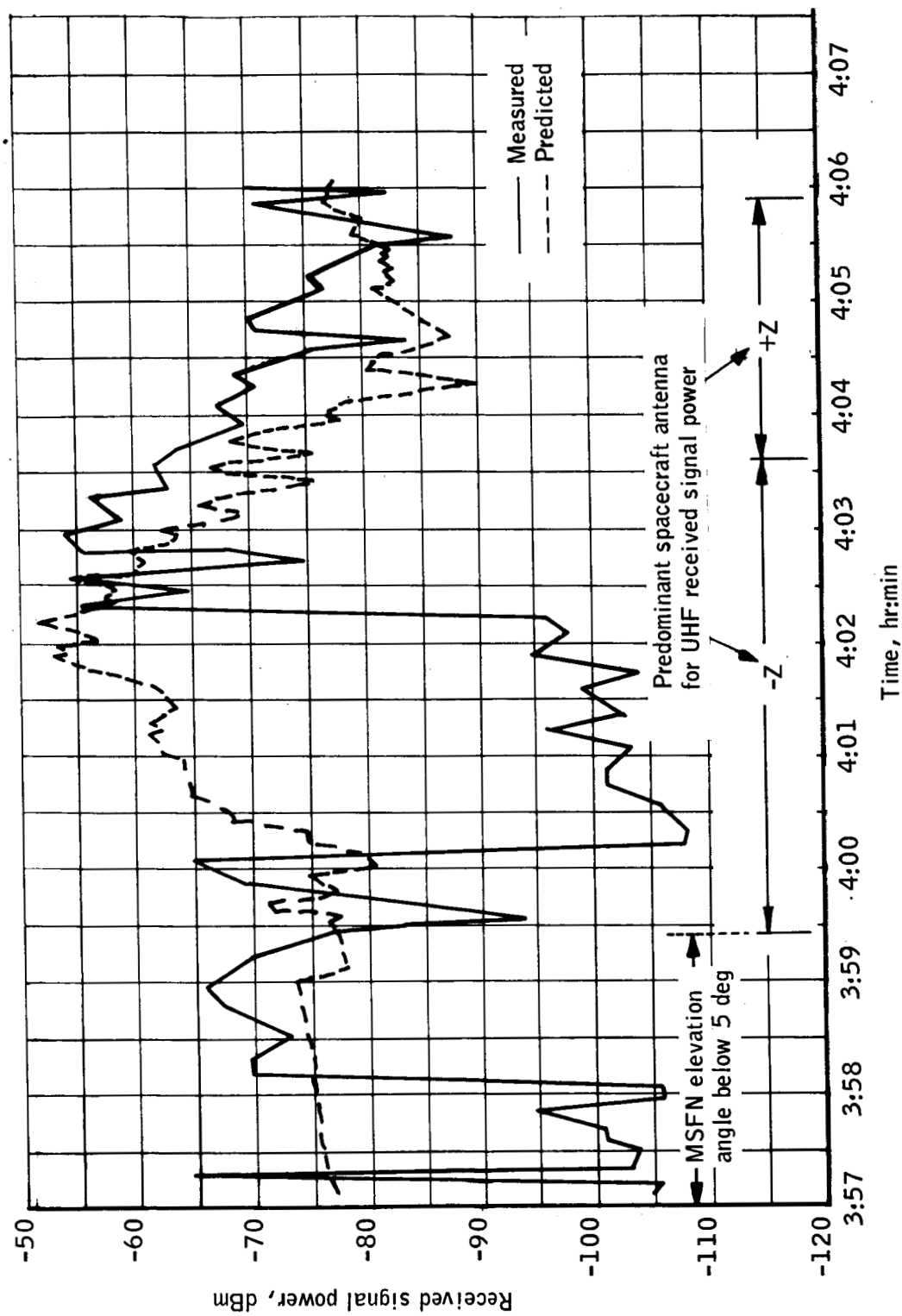


Figure 11.- Total received UHF power, Carnarvon, revolution 3.

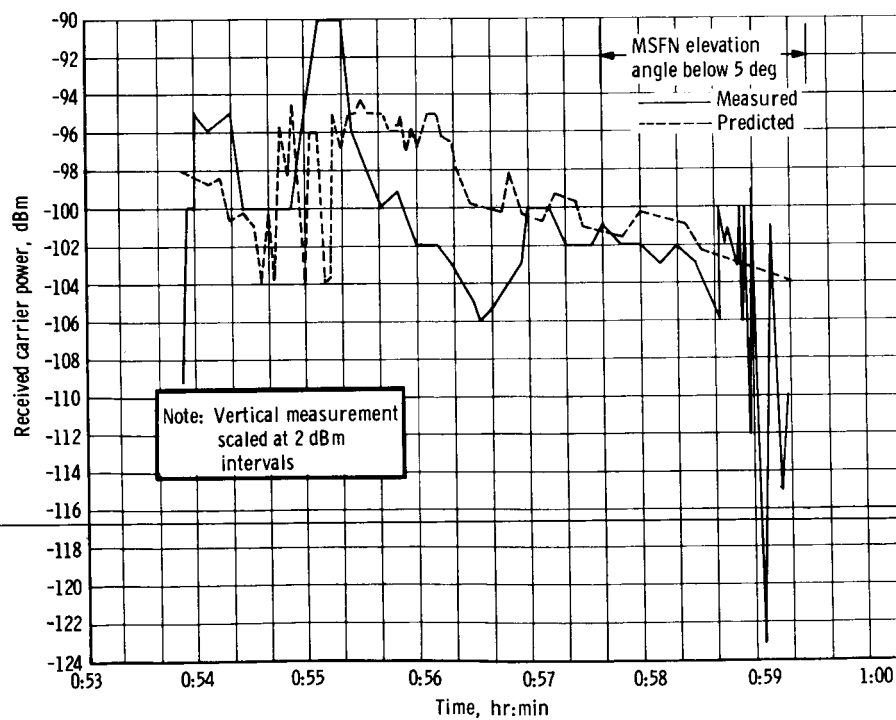
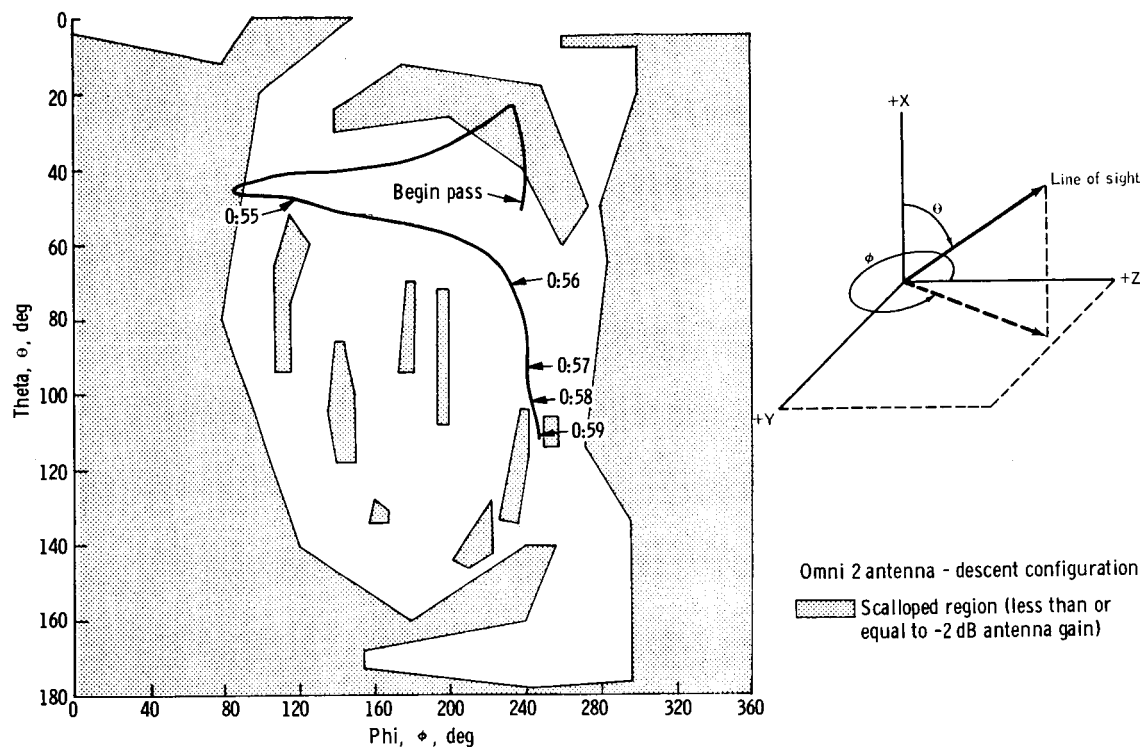


Figure 12. - Received S-band downlink carrier power and look angles, Carnarvon, revolution 1.

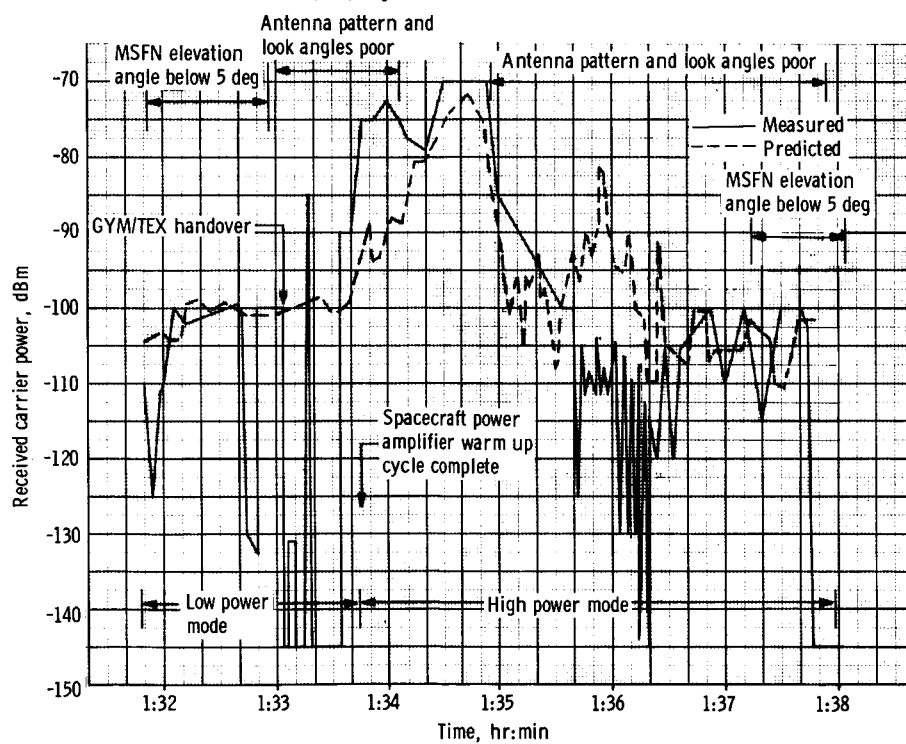
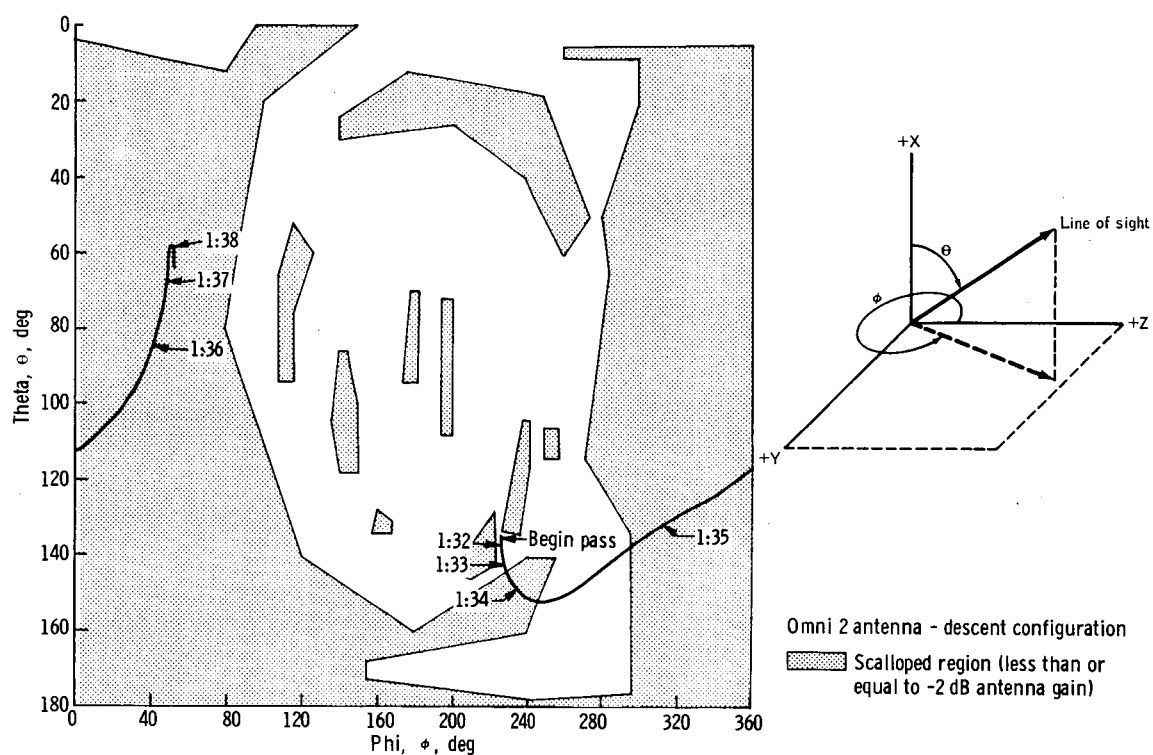


Figure 13. - Received S-band downlink carrier power and look angles, Texas, revolution 1.

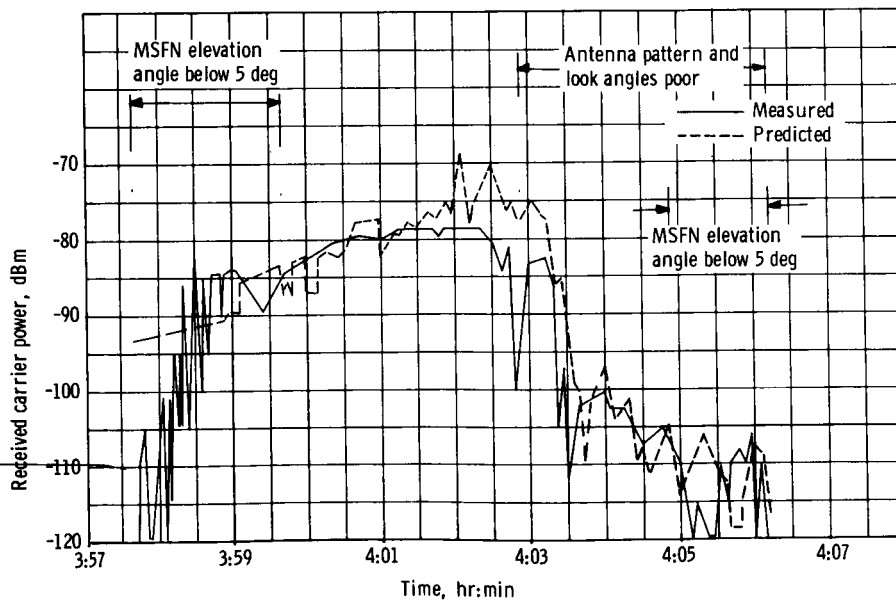
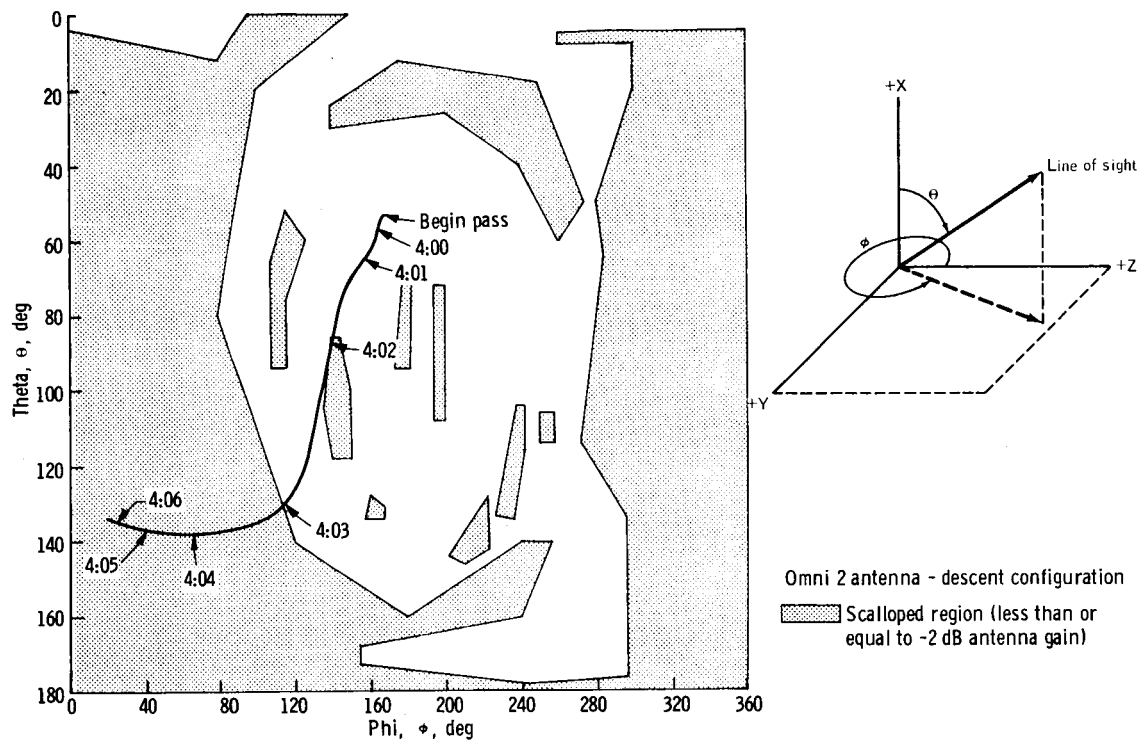


Figure 14. - Received S-band downlink carrier power and look angles, Carnarvon, revolution 3.

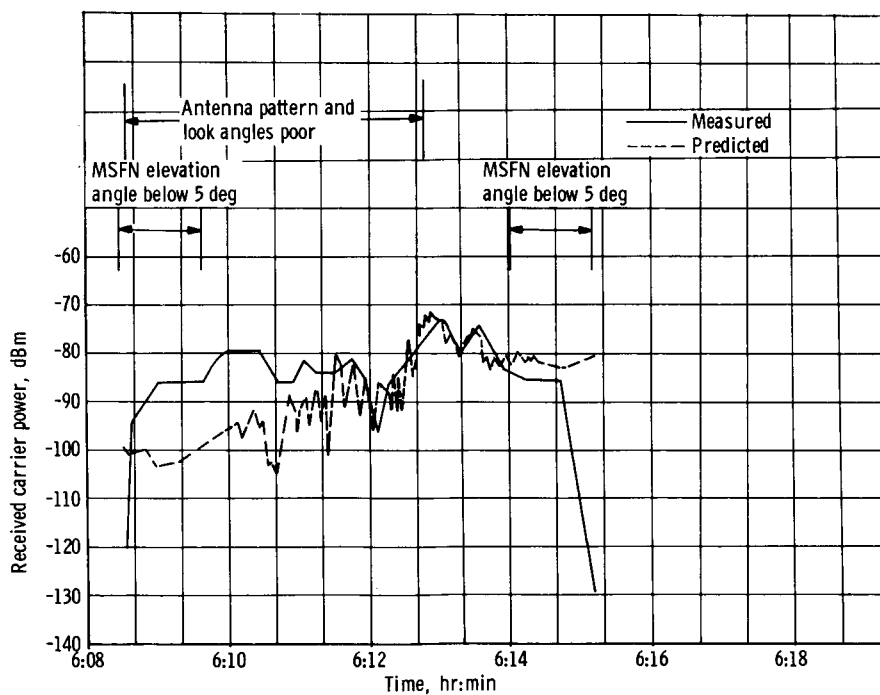
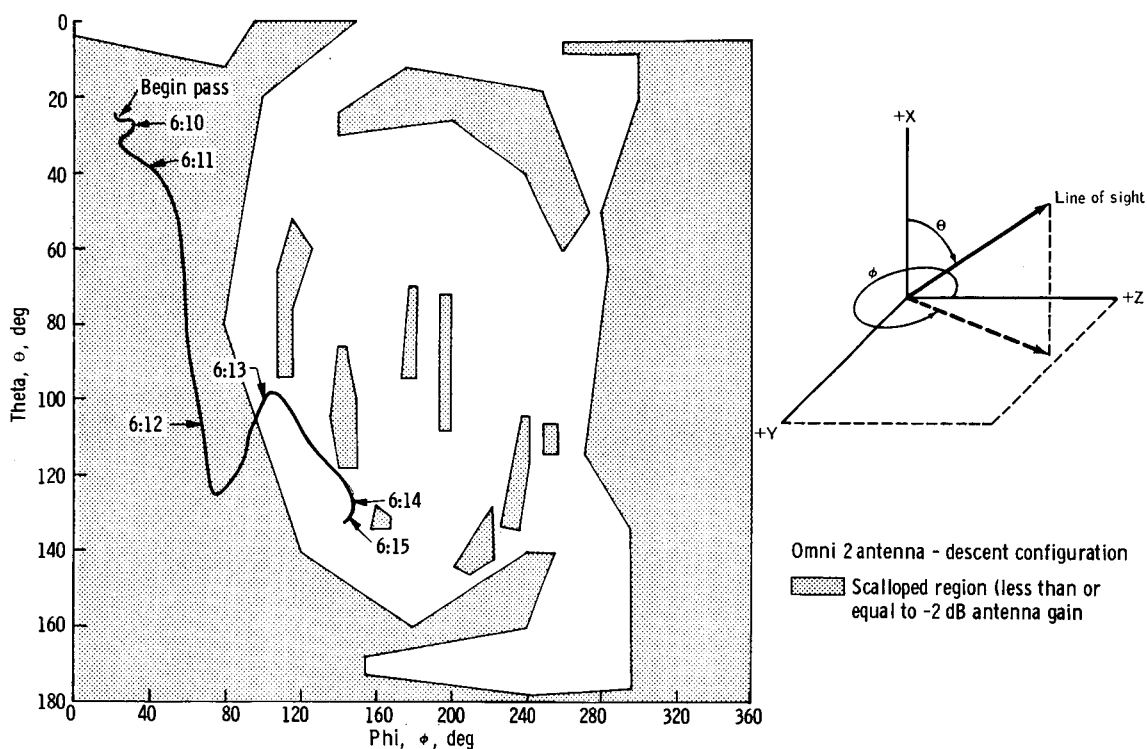


Figure 15. - Received S-band downlink carrier power and look angles, Guaymas, revolution 4.

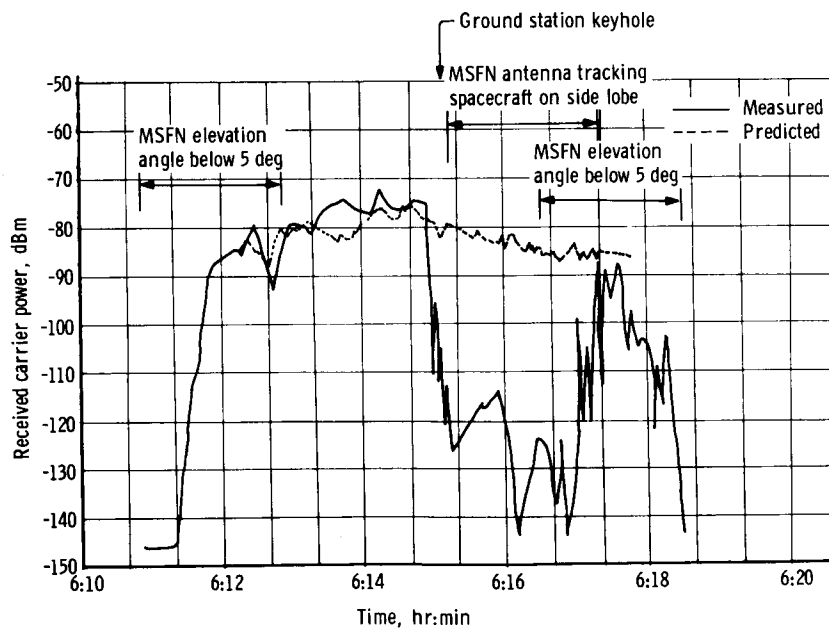
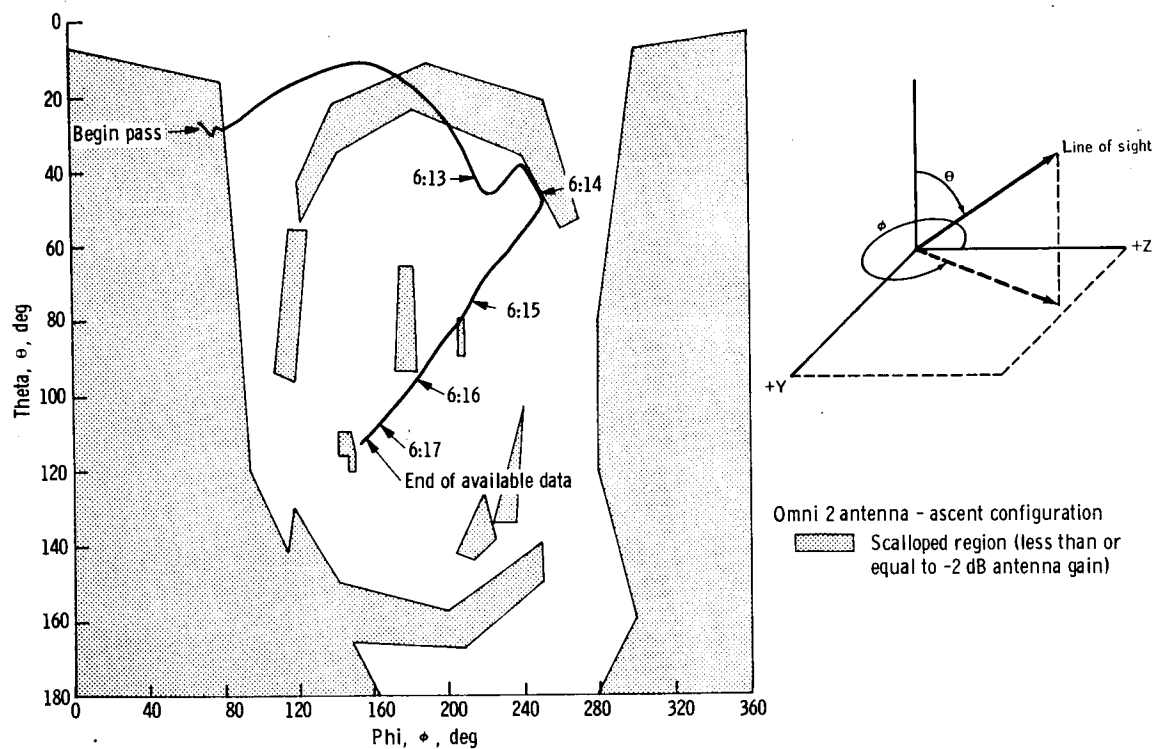


Figure 16. - Received S-band downlink carrier power and look angles, Texas, revolution 4.

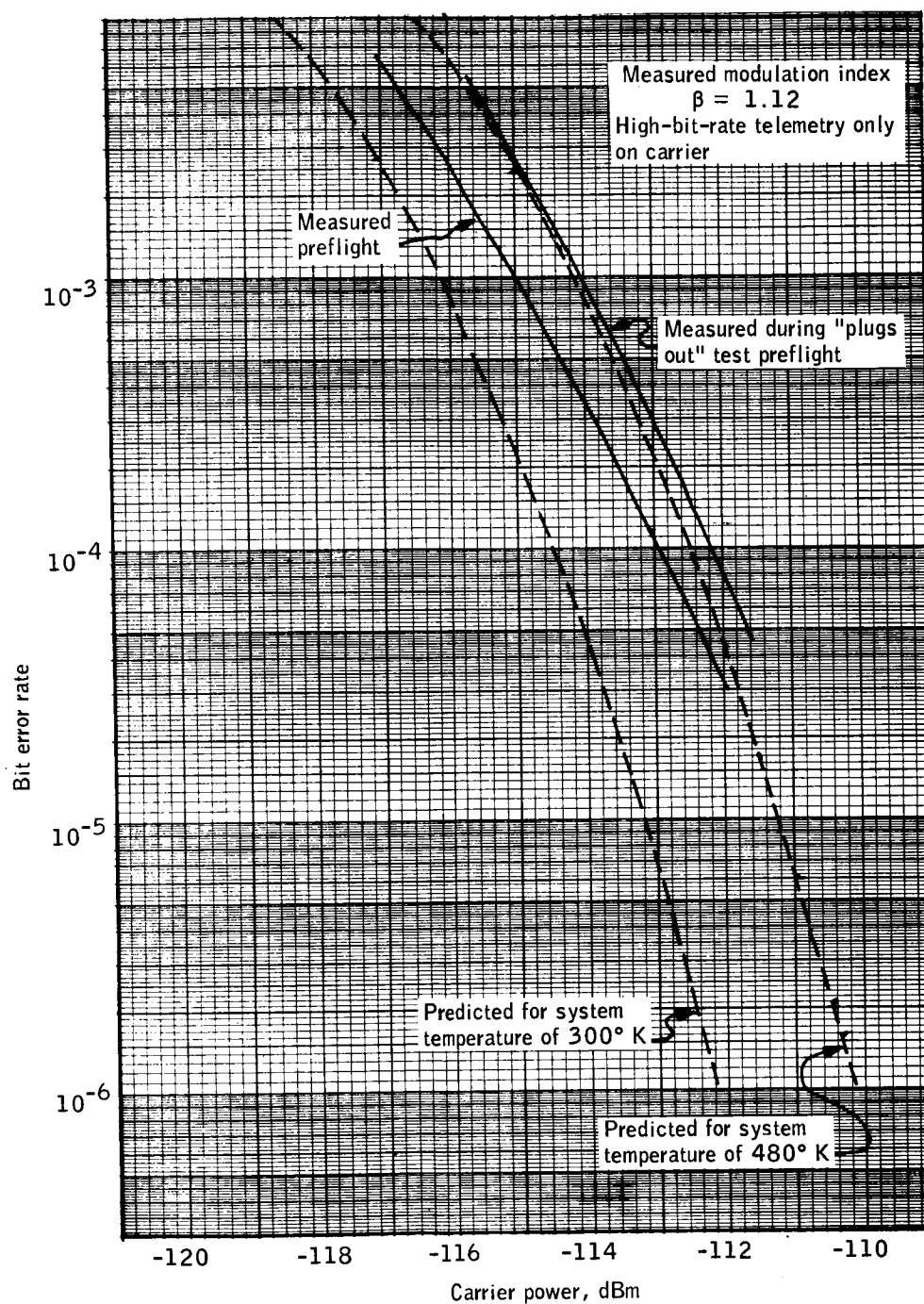


Figure 17.- Bit error rate versus recieved carrier power, primary transponder.

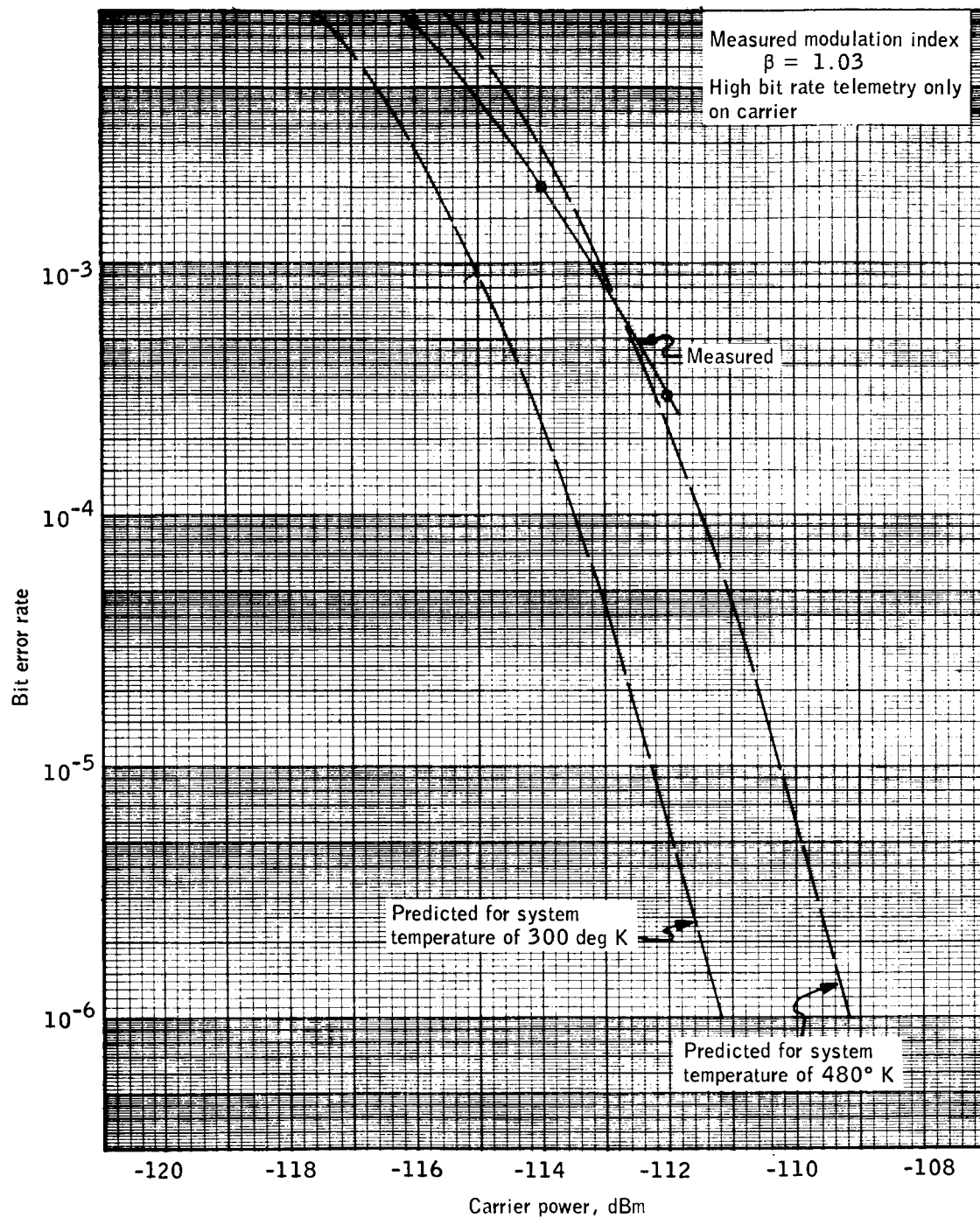


Figure 18.- Bit error rate versus power carrier power, secondary transponder.